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(54) **ULTRASONIC SENSOR AND ULTRASONIC APPARATUS**

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***B06B 1/02*** (2006.01)

(52) **U.S. Cl.**
CPC .......... ***B06B 1/0666*** (2013.01); ***B06B 1/0215*** (2013.01)

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USPC .......................................................... 310/334
See application file for complete search history.

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(57) **ABSTRACT**

An ultrasonic sensor includes an opening portion, vibrating plate covering the opening portion, piezoelectric element overlapping with the opening portion, and a coupling electrode coupled to the piezoelectric element, extended from a position overlapping the opening portion to a position not overlapping the opening portion, and having a line width smaller than a width of the piezoelectric element. The piezoelectric has a first and second line portion, and a corner portion coupling the first and second line portions, when an intersection point connects a center of gravity of the piezoelectric and the corner portion with a virtual circle inscribed in the outline of the piezoelectric is a first intersection point of a tangent line. The first intersection point with the first and second line portions are a second and third intersection points, the coupling electrode coupled to a corner portion from the second intersection point to the third intersection point.

**6 Claims, 12 Drawing Sheets**

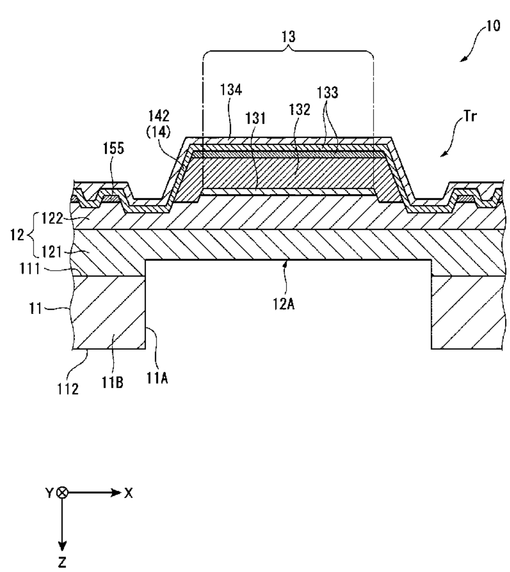
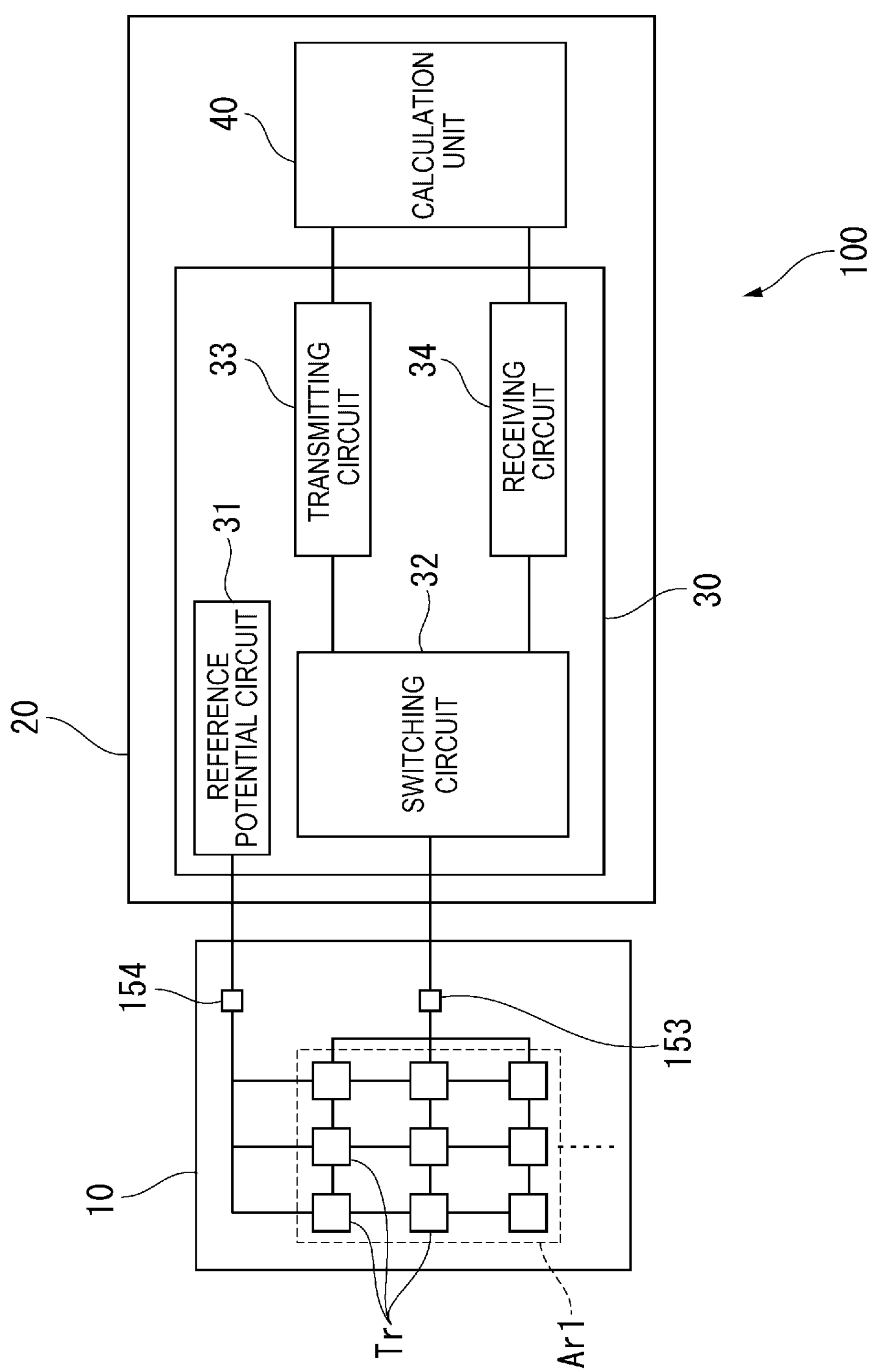
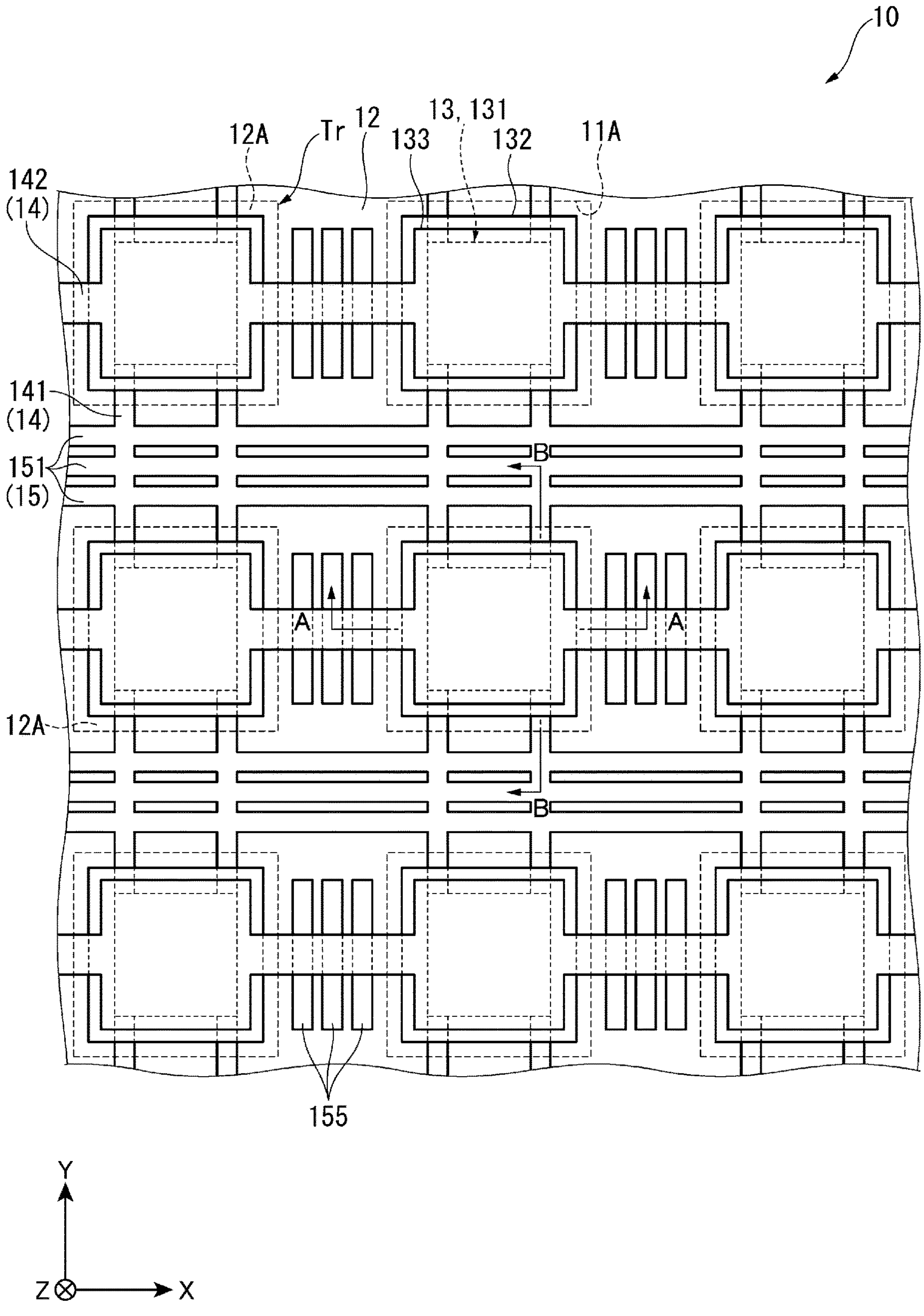


FIG. 1



CALCULATION UNIT
40
100
TRANSMITTING CIRCUIT
33
RECEIVING CIRCUIT
34
REFERENCE POTENTIAL CIRCUIT
31
32
SWITCHING CIRCUIT
30
20
154
153
10
Tr
Ar1

FIG. 2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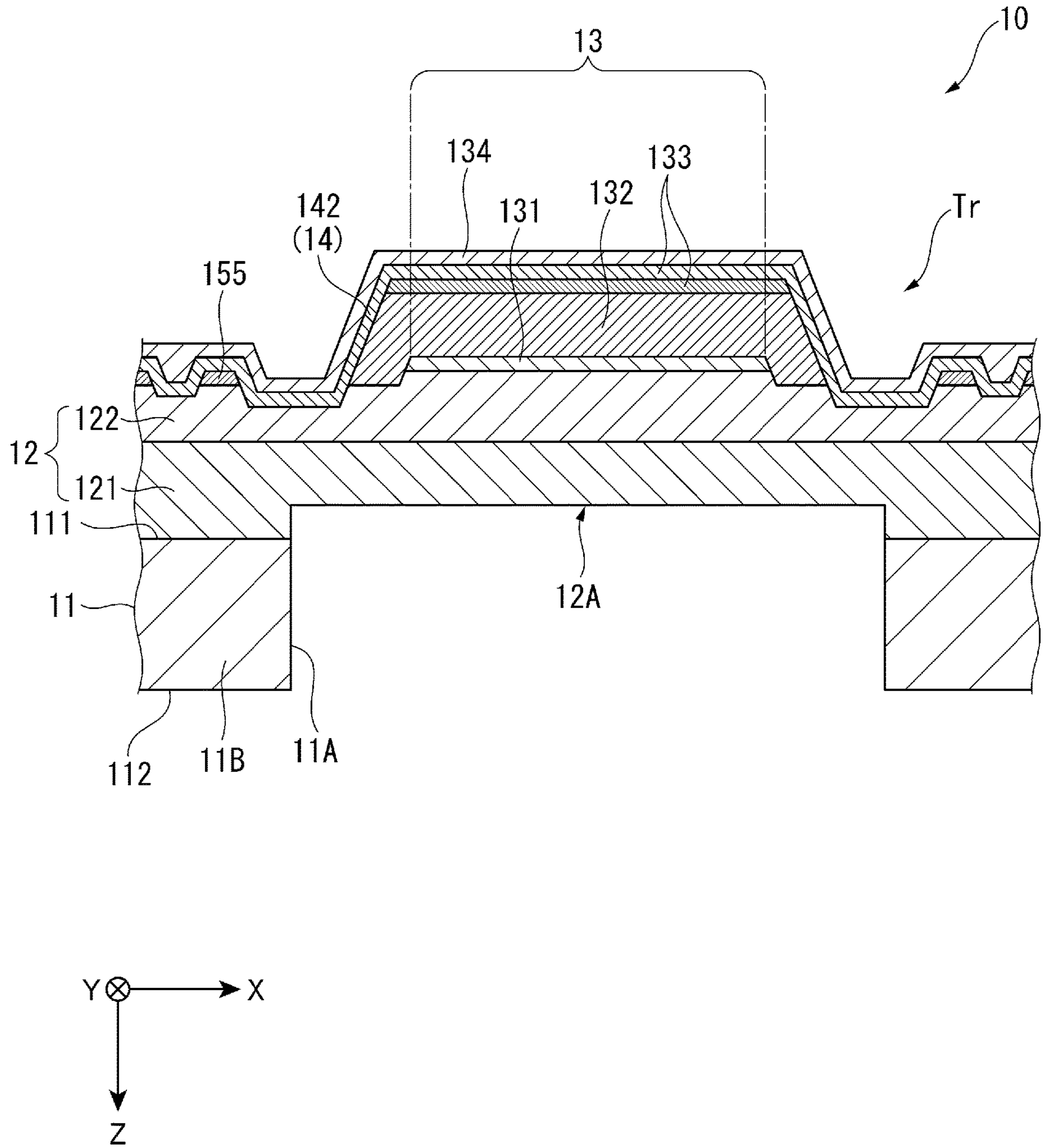
12A
Tr
12
13, 131
133
132
11A
142
(14)
141
(14)
151
(15)
B
A
A
12A
B
155
Y
Z
X

FIG. 3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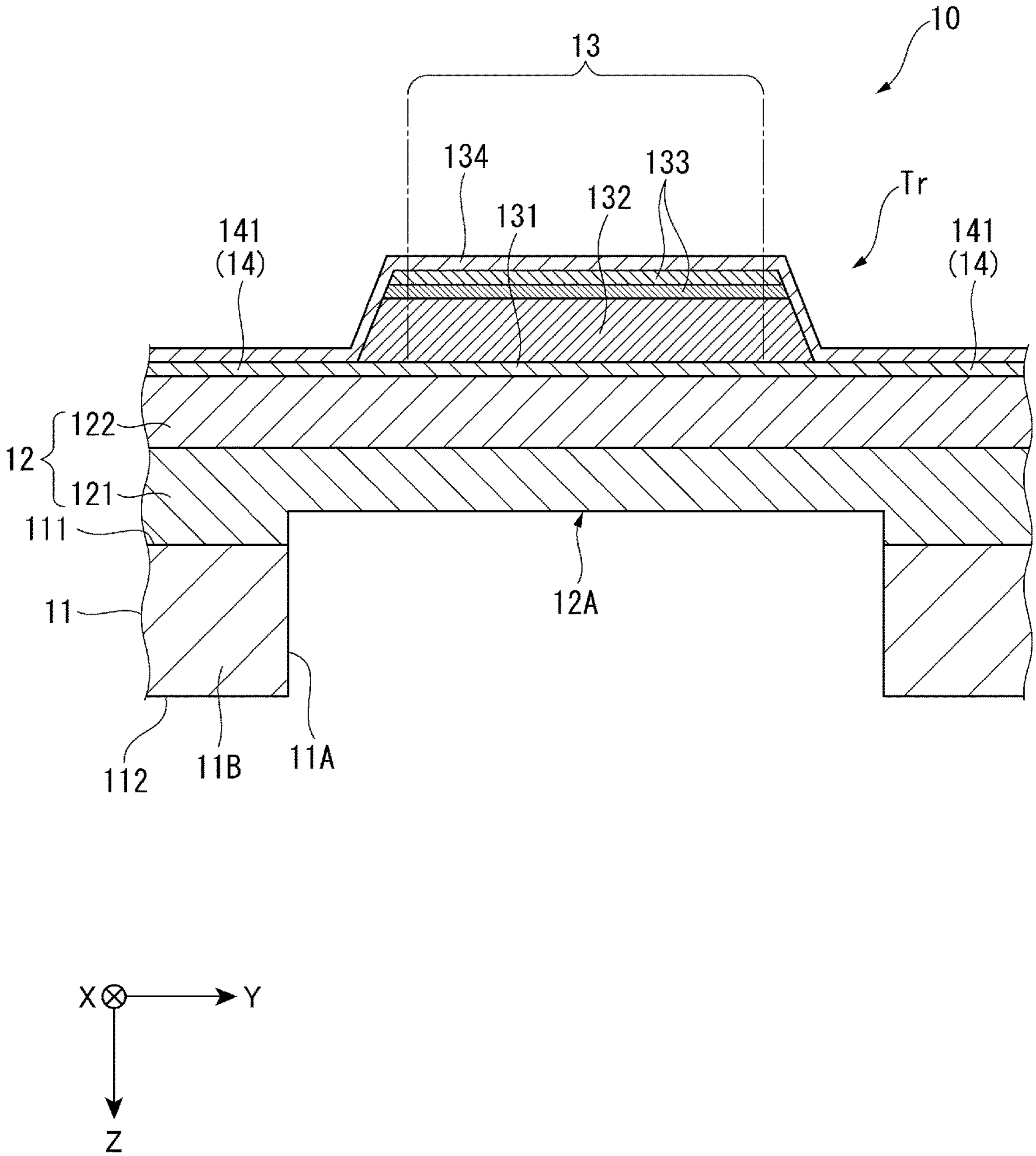
10
134
133
132
131
142
(14)
Tr
155
122
12
121
111
11
12A
112
11B
11A
Y
X
Z

FIG. 4


10
13
134
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132
131
Tr
141
(14)
141
(14)
12
122
121
111
11
12A
112
11B
11A
X
Y
Z

FIG. 5

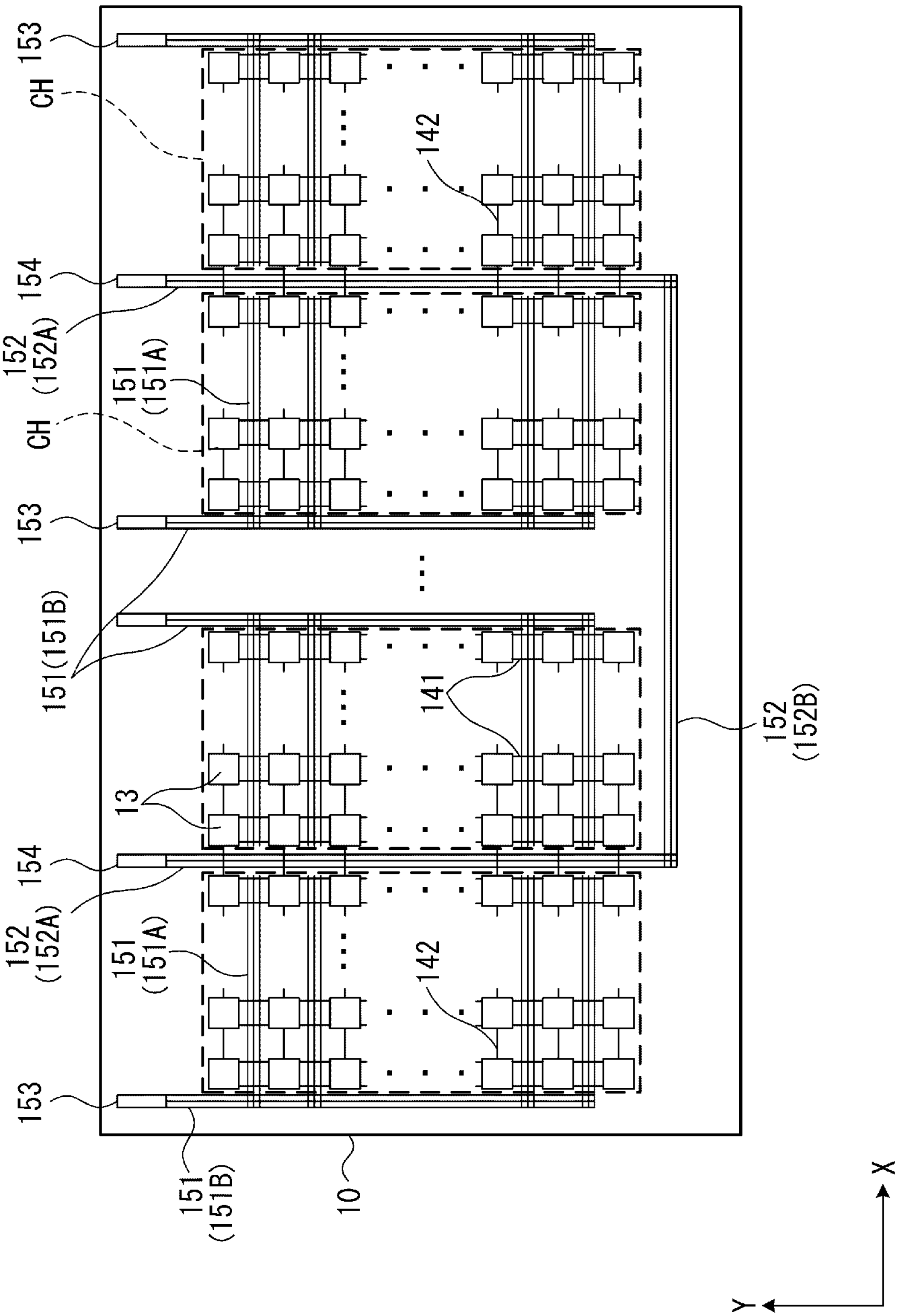
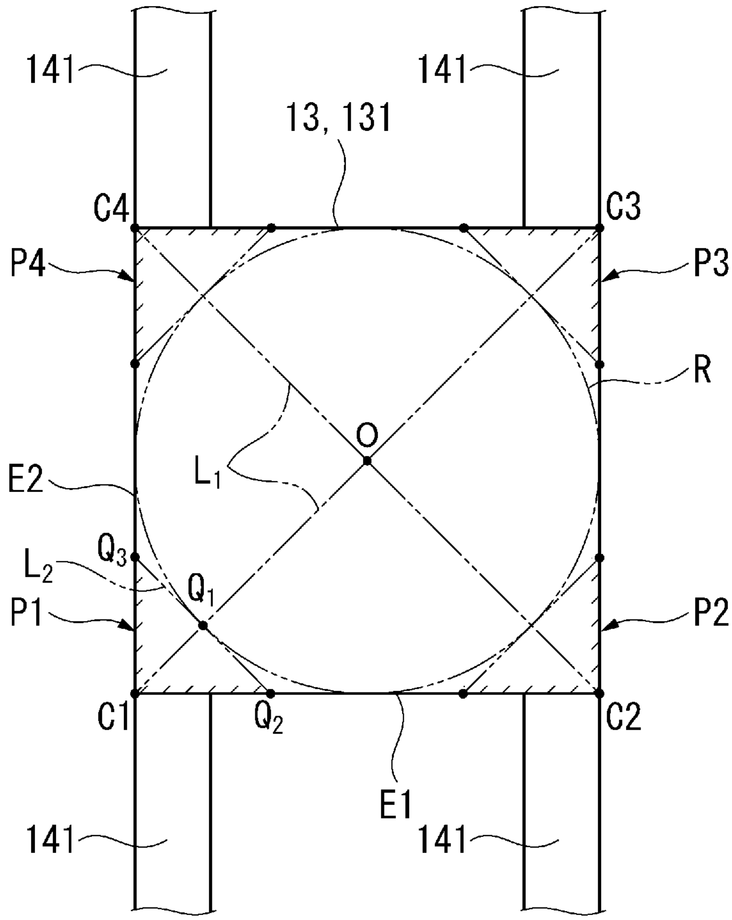

153
CH
154
152 (152A)
151 (151A)
142
153
151(151B)
141
13
152 (152B)
151 (151B)
10
X
Y

FIG. 6


141
141
13, 131
C4
C3
P4
P3
R
O
L1
E2
Q3
L2
Q1
P1
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C1
Q2
C2
E1
141
141

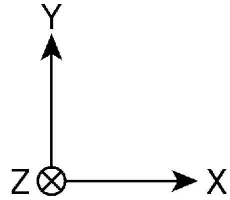

Y
Z
X

FIG. 7

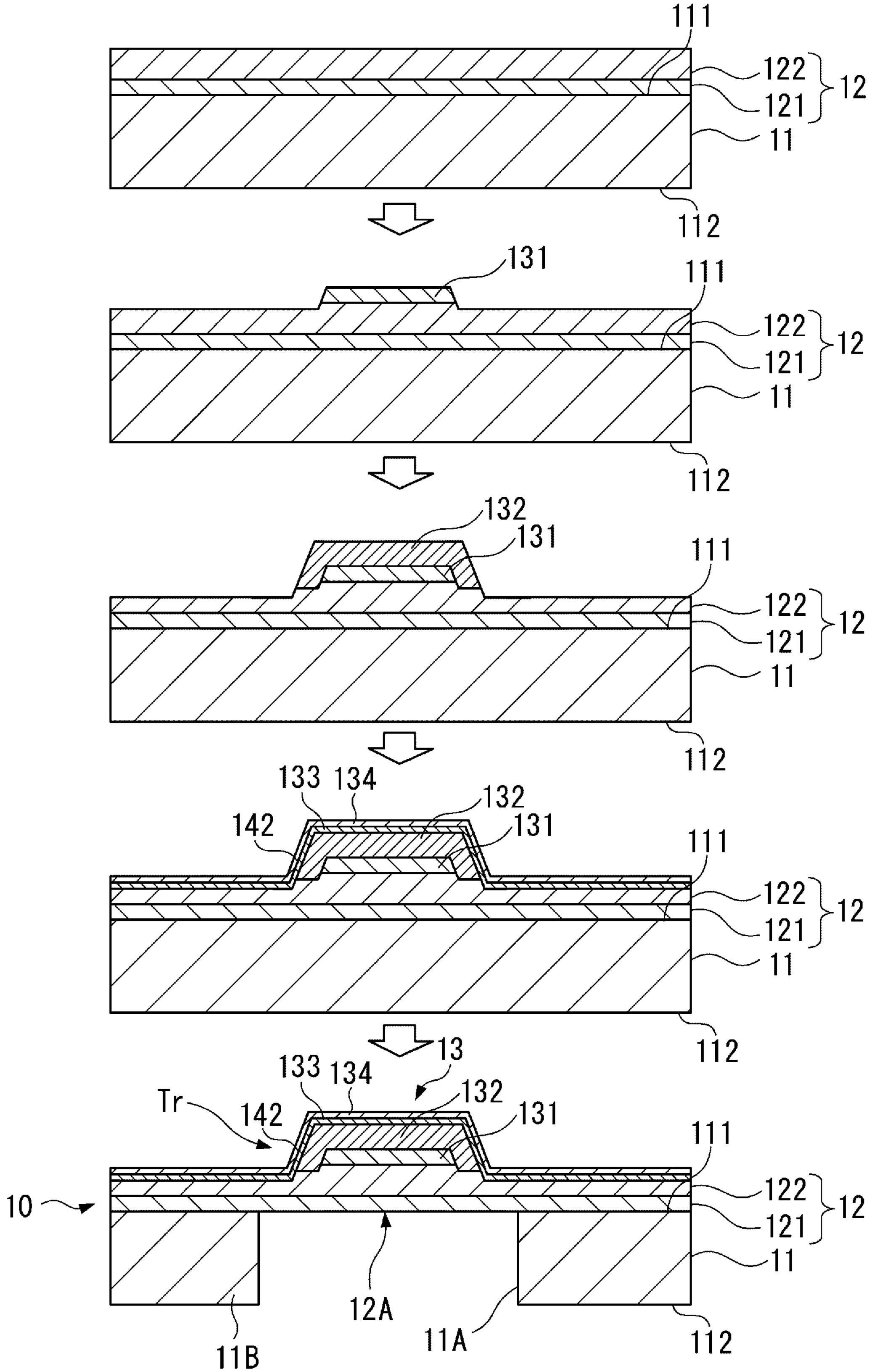
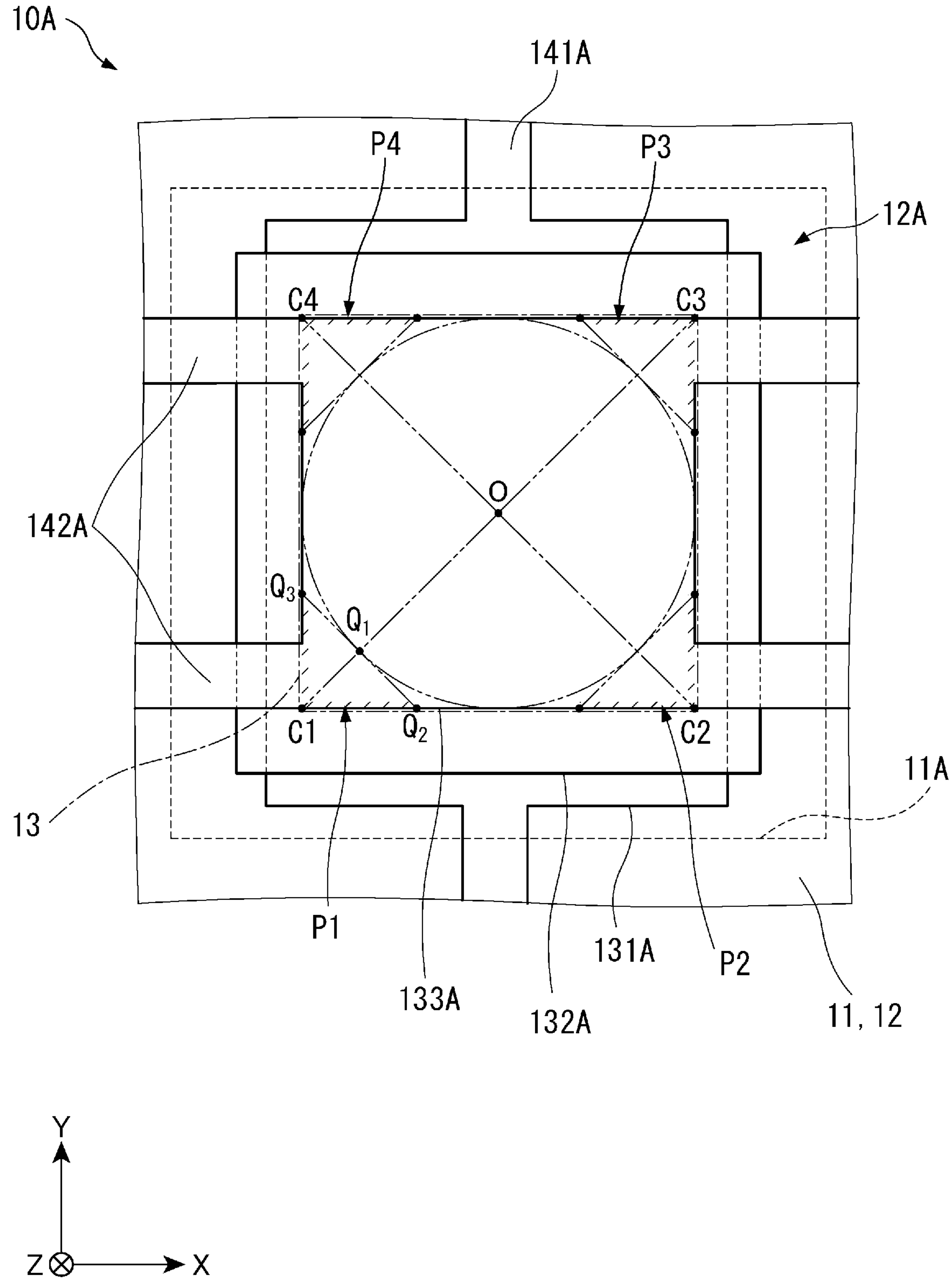


FIG. 8



10A
141A
P4
P3
12A
C4
C3
O
142A
Q3
Q1
C1
Q2
C2
11A
13
P1
133A
132A
131A
P2
11, 12
Y
Z
X

FIG. 9

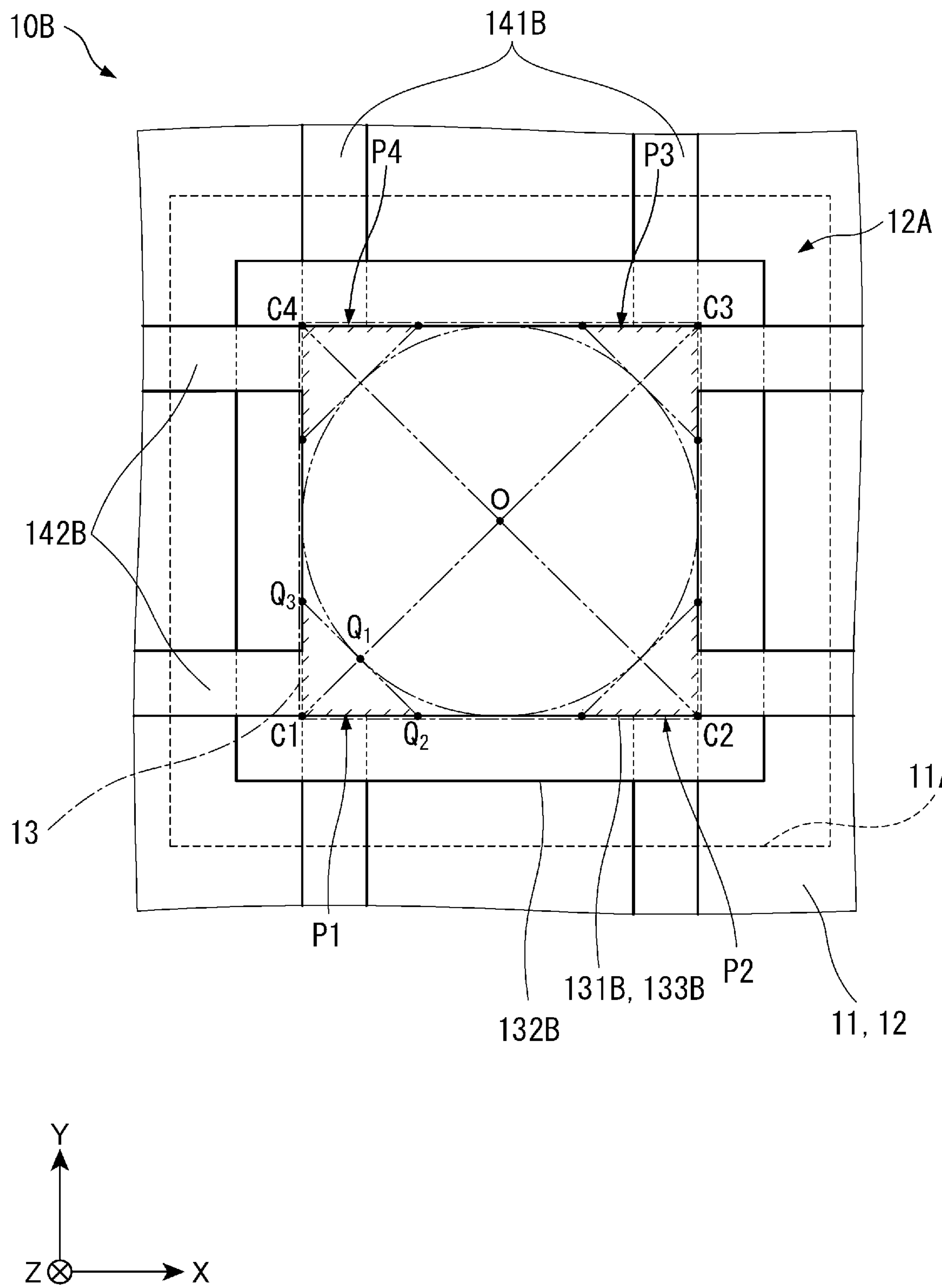

10B
141B
P4
P3
12A
C4
C3
O
142B
Q3
Q1
C1
Q2
C2
11A
13
P1
132B
131B, 133B
P2
11, 12
Y
Z
X

FIG. 10

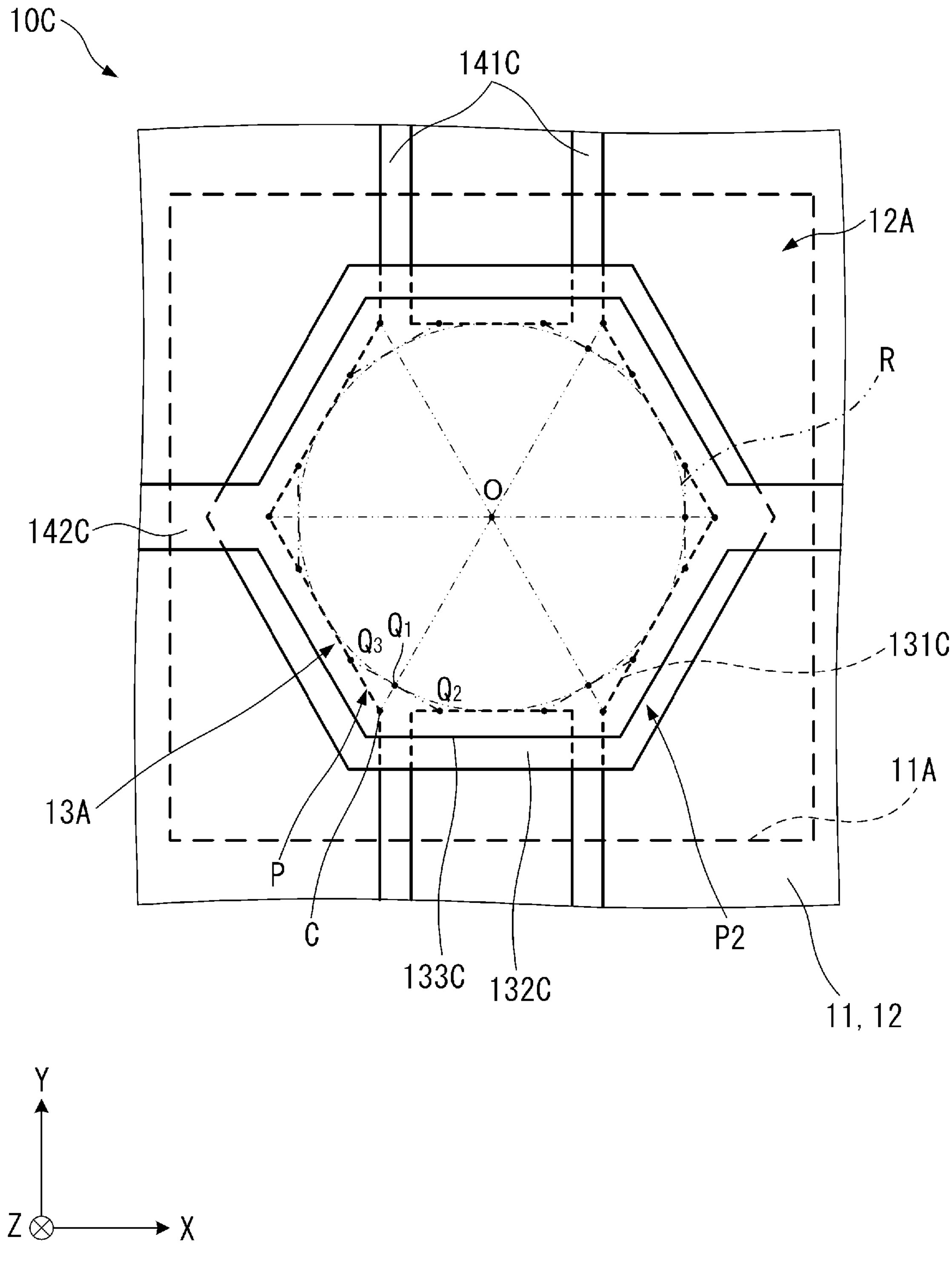

10C
141C
12A
R
O
142C
Q3
Q1
Q2
131C
13A
11A
P
C
133C
132C
P2
11, 12
Y
Z
X

FIG. 11

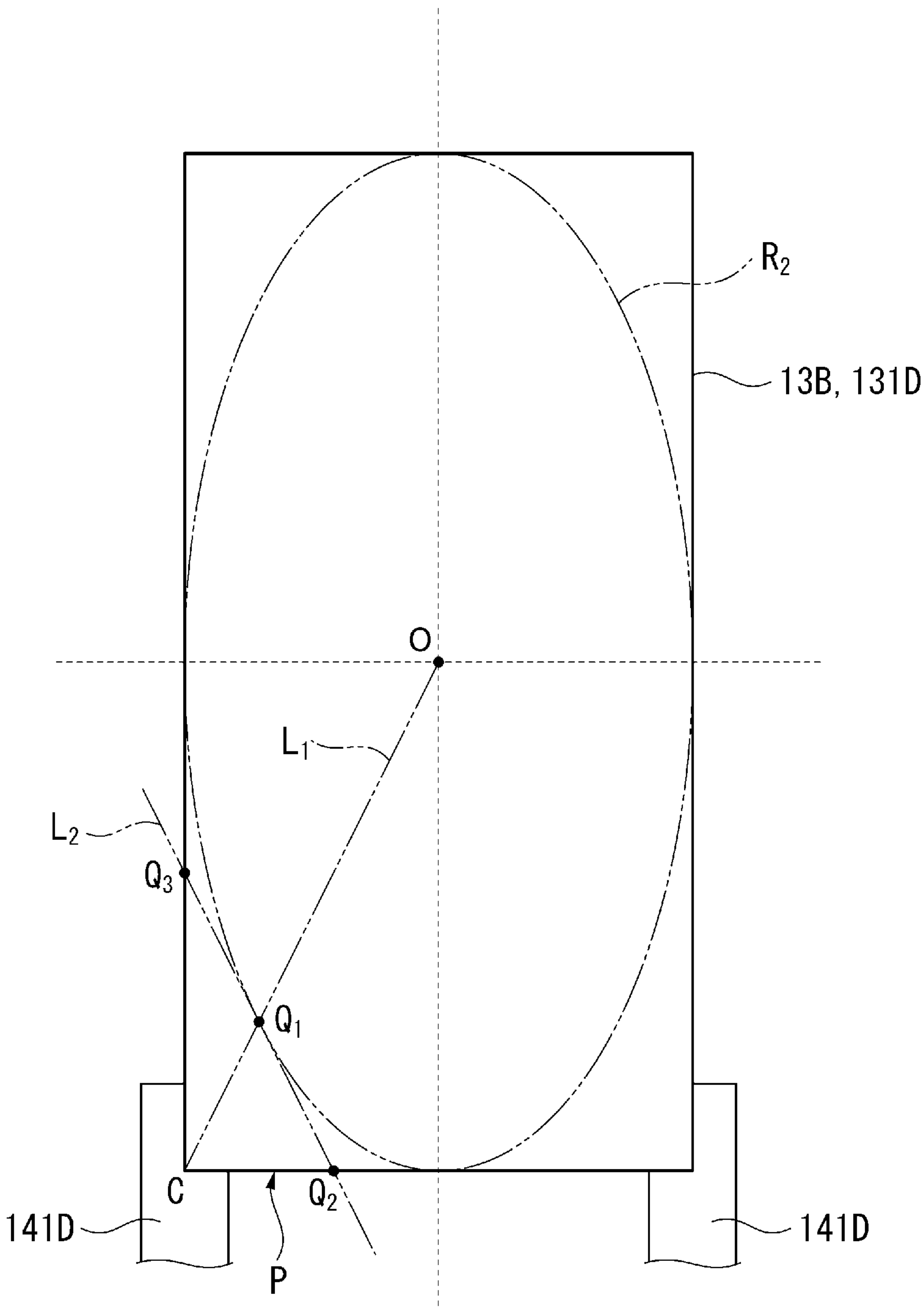
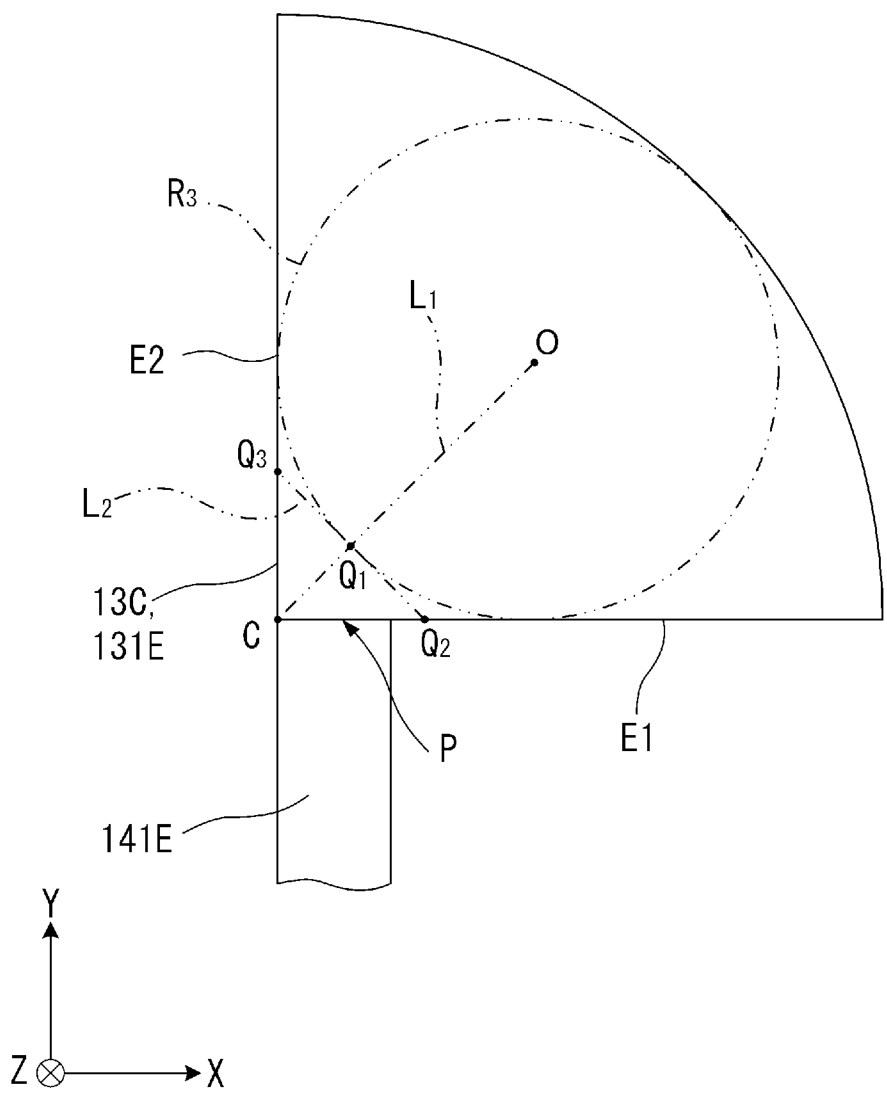


FIG. 12



# ULTRASONIC SENSOR AND ULTRASONIC APPARATUS

The present application is based on, and claims priority from JP Application Serial Number 2018-219027, filed Nov. 22, 2018, the disclosure of which is hereby incorporated by reference herein in its entirety.

## BACKGROUND

### 1. Technical Field

The present disclosure relates to an ultrasonic sensor and ultrasonic apparatus.

### 2. Related Art

In related art, ultrasonic sensors having piezoelectric elements placed on thin-film vibrating plates are known (for example, see JP-A-2017-112282).

An ultrasonic sensor disclosed in JP-A-2017-112282 includes a substrate having a rectangular opening portion, a vibrating plate closing the opening portion, and a piezoelectric element provided on the vibrating plate. The piezoelectric element has a rectangular shape in a plan view as seen from a stacking direction of the substrate, the vibrating plate, and the piezoelectric element. Further, a wiring electrode is coupled to the piezoelectric element and signals can be input to and output from the piezoelectric element.

In the piezoelectric sensor, the vibrating plate may be vibrated to output ultrasonic wave by input of a signal to the piezoelectric element. When ultrasonic wave is received by the vibrating plate, reception of the ultrasonic wave may be detected by conversion of vibration of the vibrating plate into an electrical signal using the piezoelectric element.

Further, in the piezoelectric sensor, the vibrating plate is vibrated, and thus, when the line width of the wiring electrode coupled to the piezoelectric element is larger, the vibration of the vibrating plate is hindered and vibration characteristics of the vibrating plate are affected. On the other hand, in JP-A-2017-112282, the line width of the wiring electrode coupled to the piezoelectric element is smaller than the width of the piezoelectric element, and the electrode is coupled to a center part of a side of the rectangular piezoelectric element. Thereby, vibration hinderance of the vibrating plate may be suppressed.

However, when ultrasonic wave is output from the ultrasonic sensor as disclosed in JP-A-2017-112282, stress that vibrates the vibrating plate is applied to a position overlapping with the rectangular piezoelectric element of the vibrating plate. In this case, the amount of deformation at the center point of the piezoelectric element is the maximum and the amount of deformation is smaller with distance from the center point. Accordingly, with a focus on the edge of the rectangular piezoelectric element, in the center part of the side of the rectangular shape, the amount of deformation is larger than that in a corner part. Therefore, as disclosed in JP-A-2017-112282, if the line width of the wiring electrode is made smaller than the width of the piezoelectric element and the wiring electrode is coupled to the center part of the side of the rectangular piezoelectric element, the wiring electrode may be disconnected.

## SUMMARY

An ultrasonic sensor according to a first application example includes a substrate having a first surface and a second surface in a front-back relationship with the first surface and having an opening portion penetrating from the first surface to the second surface, a vibrating plate provided on the first surface of the substrate and covering the opening portion, a piezoelectric element provided in a position overlapping with the opening portion in a plan view as seen from a direction from the first surface to the second surface in the vibrating plate, and a coupling electrode coupled to the piezoelectric element, extended from a position overlapping with the opening portion to a position not overlapping with the opening portion in the plan view, and having a line width smaller than a width of the piezoelectric element, wherein the piezoelectric element has an outline including a first line portion, a second line portion, and a corner portion coupling the first line portion and the second line portion in the plan view, when an intersection point of a first virtual line connecting a point of a center of gravity of the piezoelectric element and the corner portion with a virtual circle inscribed in the outline of the piezoelectric element is a first intersection point, an intersection point of a tangent line of the virtual circle at the first intersection point with the first line portion is a second intersection point, and an intersection point of the tangent line of the virtual circle at the first intersection point with the second line portion is a third intersection point, the coupling electrode is coupled to a corner portion neighborhood range from the second intersection point through the corner portion to the third intersection point in the outline of the piezoelectric element.

The ultrasonic sensor of the application example may include a first electrode provided on the vibrating plate, a piezoelectric material provided on the first electrode at an opposite side to the vibrating plate and covering the first electrode, and a second electrode provided on the piezoelectric material at an opposite side to the first electrode, wherein the first electrode may be provided inside of an outer peripheral edge of the second electrode in the plan view, the piezoelectric element may be formed by a part in which the first electrode, the piezoelectric material, and the second electrode overlap in the plan view, and the coupling electrode may be an electrode coupled to the first electrode.

The ultrasonic sensor of the application example may include a first electrode provided on the vibrating plate, a piezoelectric material provided on the first electrode at an opposite side to the vibrating plate, and a second electrode provided on the piezoelectric material at an opposite side to the first electrode, wherein the second electrode may be provided inside of an outer peripheral edge of the first electrode in the plan view, the piezoelectric element may be formed by apart in which the first electrode, the piezoelectric material, and the second electrode overlap in the plan view, and the coupling electrode may be an electrode coupled to the second electrode.

The ultrasonic sensor of the application example may include a first electrode provided on the vibrating plate, a piezoelectric material provided on the first electrode at an opposite side to the vibrating plate, and a second electrode provided on the piezoelectric material at an opposite side to the first electrode, wherein the second electrode may have the same shape as the first electrode and overlap with the first electrode in the plan view, the piezoelectric element may be formed by apart in which the first electrode, the piezoelectric material, and the second electrode overlap in the plan view, and the coupling electrode may include a first coupling electrode coupled to the first electrode and a second coupling electrode coupled to the second electrode.

The ultrasonic sensor of the application example may further include a terminal portion coupled to a circuit board, and a bypass electrode coupling the terminal portion and the coupling electrode, wherein the line width of the coupling electrode and a line width of the bypass electrode may be the same width.

An ultrasonic apparatus of a second application example includes the above described ultrasonic sensor of the first application example, and a control unit that controls the ultrasonic sensor.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block diagram showing a schematic configuration of a distance measuring apparatus as an example of an ultrasonic apparatus of a first embodiment.

FIG. **2** is a plan view showing a part of an ultrasonic sensor of the first embodiment.

FIG. **3** is a sectional view of the ultrasonic sensor cut along line A-A in FIG. **2**.

FIG. **4** is a sectional view of the ultrasonic sensor cut along line B-B in FIG. **2**.

FIG. **5** is a plan view showing an example of a wiring configuration of the ultrasonic sensor of the first embodiment.

FIG. **6** is a plan view for explanation of coupling positions of first wiring electrodes to a piezoelectric element of the first embodiment.

FIG. **7** shows respective steps for manufacturing the ultrasonic sensor of the first embodiment.

FIG. **8** is a partially enlarged plan view of an ultrasonic sensor according to a second embodiment.

FIG. **9** is a partially enlarged plan view of an ultrasonic sensor according to a third embodiment.

FIG. **10** is a partially enlarged plan view of an ultrasonic sensor according to modified example 2.

FIG. **11** shows a position relationship between a piezoelectric element and coupling electrodes of another ultrasonic sensor according to modified example 2.

FIG. **12** shows a position relationship between a piezoelectric element and a coupling electrode of another ultrasonic sensor according to modified example 2.

## DESCRIPTION OF EXEMPLARY EMBODIMENTS

### First Embodiment

As below, the first embodiment will be explained.

FIG. **1** is the block diagram showing the schematic configuration of a distance measuring apparatus **100** as the example of the ultrasonic apparatus of the first embodiment.

As shown in FIG. **1**, the distance measuring apparatus **100** of the embodiment includes an ultrasonic sensor **10** and a control unit **20** that controls the ultrasonic sensor **10**. In the distance measuring apparatus **100**, the control unit **20** controls the ultrasonic sensor **10** via a drive circuit **30** and transmits ultrasonic wave from the ultrasonic sensor **10**. Further, when the ultrasonic wave is reflected by an object and reflected wave is received by the ultrasonic sensor **10**, the control unit **20** calculates a distance from the ultrasonic sensor **10** to the object based on a time from the transmission time of the ultrasonic wave to the reception time of the ultrasonic wave.

As below, a configuration of the distance measuring apparatus **100** will be specifically explained.

Configuration of Ultrasonic Sensor **10**

FIG. **2** is the plan view showing the part of the ultrasonic sensor **10**. FIG. **3** is the sectional view of the ultrasonic sensor **10** cut along line A-A in FIG. **2**. FIG. **4** is the sectional view of the ultrasonic sensor **10** cut along line B-B in FIG. **2**.

As shown in FIG. **3**, the ultrasonic sensor **10** includes a substrate **11**, a vibrating plate **12**, a piezoelectric element **13**, and wiring electrodes **14**. Further, as shown in FIG. **2**, the ultrasonic sensor **10** includes bypass electrodes **15** coupled to the wiring electrodes **14**.

Configuration of Substrate **11**

The substrate **11** is a plate formed using a semiconductor substrate of Si or the like and having a predetermined thickness for supporting the vibrating plate **12**. The substrate **11** has a first surface **111** and a second surface **112** in a front-back relation with the first surface **111**. Here, in the following explanation, a direction from the first surface **111** toward the second surface **112** is referred to as "Z direction", a direction orthogonal to the Z direction is referred to as "X direction", and a direction orthogonal to the X direction and the Z direction is referred to as "Y direction". The first surface **111** and the second surface **112** are surfaces parallel to the XY-plane.

Opening portions **11**A penetrating from the first surface **111** to the second surface **112** along the Z direction are provided in the substrate **11**. A plurality of the opening portions **11**A are provided along the X direction and the Y direction. That is, the opening portions **11**A are arranged in a two-dimensional array form in the substrate **11**.

The vibrating plate **12** is provided at the first surface **111** sides of the opening portions **11**A. Of the substrate **11**, parts without the opening portions **11**A form wall portions **11**B and the vibrating plate **12** is stacked and supported on the wall portions **11**B.

Configuration of Vibrating Plate **12**

The vibrating plate **12** is formed using e.g. $SiO_2$, a stacking structure of $SiO_2$ and $ZrO_2$, or the like. In the example shown in FIGS. **3** and **4**, the vibrating plate **12** is formed using a stacking structure of $SiO_2$ and $ZrO_2$, and includes a first vibrating plate **121** placed at the substrate **11** side and a second vibrating plate **122** placed on the first vibrating plate **121** at an opposite side to the substrate **11**.

The thickness of the vibrating plate **12** along the Z direction is sufficiently smaller than the thickness of the substrate **11**. The vibrating plate **12** is supported by the wall portions **11**B of the substrate **11** forming the opening portions **11**A, and thereby, as described above, closes the −Z sides of the opening portions **11**A. Of the vibrating plate **12**, the parts overlapping with the opening portions **11**A in a plan view as seen from the Z direction, i.e., the parts closing the opening portions **11**A form vibrating portions **12**A. The vibrating portions **12**A of the vibrating plate **12** are surrounded by the wall portions **11**B, and the outer edges of the vibrating portions **12**A are defined by the opening portions **11**A. The vibrating portions **12**A serve as vibrating regions that can vibrate by the piezoelectric element **13**. Note that, in the following explanation, the plan view as seen from the Z direction is simply referred to as "plan view".

Configuration of Piezoelectric Element **13**

On the −Z side surface of the vibrating plate **12**, first electrodes **131**, the wiring electrodes **14**, and the bypass electrodes **15** are provided. Further, on the −Z sides of the first electrodes **131**, piezoelectric materials **132** are provided. Furthermore, on the −Z sides of the piezoelectric materials **132**, second electrodes **133** are provided.

Here, as shown in FIG. **2**, the first electrodes **131** are provided in center parts of the vibrating portions **12**A and have rectangular shapes in the plan view.

Further, the piezoelectric materials **132** are provided to cover the entire −Z side surfaces of the first electrodes **131** and parts along the outer peripheral edges of the piezoelectric materials **132** are located on the vibrating plate **12**. That is, the first electrodes **131** are placed inside of the outer peripheral edges of the piezoelectric materials **132** in the plan view.

Those piezoelectric materials **132** are formed by repeated application and firing of piezoelectric materials onto the vibrating plate **12**, formation of a piezoelectric film having a predetermined thickness, and patterning by etching. Therefore, as shown in FIGS. **3** and **4**, the parts along the outer peripheral edges of the piezoelectric materials **132** are tapered surfaces inclined like mountainsides. Of the −Z side surfaces of the piezoelectric materials **132**, the other parts than the tapered surfaces form piezoelectric material upper surfaces substantially parallel to the XY-plane. As shown in FIGS. **3** and **4**, the outer peripheral edges of the piezoelectric material upper surfaces are located outside of the outer peripheral edges of the first electrodes **131**. That is, the first electrodes **131** are placed inside of the outer peripheral edges of the piezoelectric material upper surfaces in the plan view.

The second electrodes **133** are provided on the piezoelectric material upper surfaces of the piezoelectric materials **132**. That is, in the embodiment, in the plan view, the second electrodes **133** are larger than the first electrodes **131**, and the first electrodes **131** are placed inside of the outer peripheral edges of the second electrodes **133**. Note that, in FIGS. **3** and **4**, an example of the second electrode **133** formed by two layers is shown, however, the second electrode may be formed by a single layer.

In the above described configuration, in the plan view, the piezoelectric element **13** is formed by apart in which the first electrode **131**, the piezoelectric material **132**, and the second electrode **133** overlap. That is, the piezoelectric element **13** of the embodiment refers to an active part in which the piezoelectric material **132** is driven when a voltage is applied to the first electrode **131** and the second electrode **133**.

In the embodiment, the first electrode **131** is smaller than the piezoelectric material **132** and the second electrode **133**, and placed inside of the outer peripheral edge of the piezoelectric material **132** and the outer peripheral edge of the second electrode **133**. Therefore, the entire first electrode **131**, a part of the piezoelectric material **132** overlapping with the first electrode **131** in the plan view, and a part of the second electrode **133** overlapping with the first electrode **131** in the plan view form the piezoelectric element **13**.

Here, one ultrasonic transducer Tr is formed by the single vibrating portion **12**A in the vibrating plate **12** and the piezoelectric element **13** provided on the vibrating portion **12**A. In the embodiment, as shown in FIG. **2**, the piezoelectric elements **13** are placed for the respective vibrating portions **12**A. That is, in the ultrasonic sensor **10**, a plurality of the ultrasonic transducers Tr are placed along the X direction and the Y direction.

In the ultrasonic transducer Tr having the above described configuration, a voltage is applied between the first electrode **131** and the second electrode **133**, and thereby, the piezoelectric element **13** expands and contracts and the vibrating portion **12**A of the vibrating plate **12** with the piezoelectric element **13** provided thereon vibrates at a frequency according to the opening width of the opening portion **11**A or the like. Thereby, ultrasonic wave is transmitted from the +Z side of the vibrating portion **12**A.

Or, when ultrasonic wave is input to the opening portion **11**A, the vibrating portion **12**A vibrates by the ultrasonic wave and a potential difference is produced between the upside and the downside of the piezoelectric material **132**. Therefore, the potential difference produced between the first electrode **131** and the second electrode **133** is detected, and thereby, the ultrasonic wave can be detected (received).

Further, in the embodiment, as shown in FIGS. **3** and **4**, a protective film **134** covering the piezoelectric element **13** is provided. The protective film **134** is a film that protects the second electrode **133** and parts not covered by a second wiring electrode **142**, which will be described later, coupled to the second electrode **133** of the −Z side surface of the piezoelectric material **132**. The piezoelectric material **132** is covered by the second electrode **133**, the second wiring electrode **142**, and the protective film **134**, and thereby, breakage such as cracking of the piezoelectric material **132** can be suppressed.

Configurations of Wiring Electrode **14** and Bypass Electrode **15**

FIG. **5** shows the example of the wiring configuration of the ultrasonic sensor **10**.

As shown in FIGS. **2** and **5**, the wiring electrode **14** includes a first wiring electrode **141** coupled to the first electrode **131** and the second wiring electrode **142** coupled to the second electrode **133**.

The bypass electrode **15** is an electrode coupled to the wiring electrode **14** and coupling the piezoelectric element **13** to the drive circuit **30**. Specifically, the bypass electrode **15** includes a first bypass electrode **151** coupled to the first wiring electrode **141** and a second bypass electrode **152** coupled to the second wiring electrode **142**.

The first wiring electrode **141** is a coupling electrode coupled to the piezoelectric element **13**, coupled to the first electrode **131**, and extended from a position overlapping with the opening portion **11**A in the plan view to a position not overlapping with the opening portion **11**A, i.e., a position overlapping with the wall portion **11**B. More specifically, in the embodiment, the first wiring electrode **141** is elongated along the Y direction and couples the first electrodes **131** arranged in the Y direction. In the embodiment, two of the first wiring electrodes **141** are provided between the two first electrodes **131** arranged in the Y direction, and respectively couple corner portions of the first electrodes **131**.

As below, coupling positions of the first wiring electrodes **141** to the first electrode **131** will be explained further in detail according to FIG. **6**.

FIG. **6** is the plan view for explanation of the coupling positions of the first wiring electrodes **141** to the piezoelectric element **13**.

In FIG. **6**, O is a point of the center of gravity of the piezoelectric element **13** in the plan view. R is a virtual circle inscribed in the respective sides of the piezoelectric element **13**. Further, an intersection point of a first virtual line $L_1$ connecting one corner portion C**1** and the point of the center of gravity O of the piezoelectric element **13** with the virtual circle R is a first intersection point $Q_1$, and a tangent line of the virtual circle R at the first intersection point $Q_1$ is a second virtual line $L_2$.

Furthermore, two sides of the piezoelectric element **13** with the corner portion C**1** in between are respectively a first line portion E**1** and a second line portion E**2**, and an intersection point of the second virtual line $L_2$ with the first line portion E**1** is a second intersection point $Q_2$ and an intersection point of the second virtual line $L_2$ with the second line portion E2 is a third intersection point $Q_3$.

Note that, in the embodiment, the first electrode **131** and the piezoelectric element **13** coincide in the plan view and the point of the center of gravity O is also the center of gravity of the first electrode **131** and the virtual circle R is also a virtual circle inscribed in the outer peripheral edge of the first electrode **131**. Further, the corner portion C**1** is also a corner portion of the first electrode **131** and the first line portion E**1** and the second line portion E**2** are also two sides with the corner portion of the first electrode **131** in between.

In the embodiment, the first wiring electrode **141** is coupled to a corner portion neighborhood range P**1** from the second intersection point $Q_2$ through the corner portion C**1** to the third intersection point $Q_3$ of the outer peripheral edge of the piezoelectric element **13**, i.e., the outer peripheral edge of the first electrode **131**.

Further, the line width of the first wiring electrode **141** in a direction orthogonal to the longitudinal direction is smaller than the width of the piezoelectric element **13** in the same direction. In the embodiment, the first wiring electrode **141** is an electrode extended along the Y direction, and the width in the X direction is the line width of the first wiring electrode **141** and smaller than the width of the piezoelectric element **13** in the X direction. It is preferable that the line width of the first wiring electrode **141** is equal to or smaller than the length of the line segment connecting the second intersection point $Q_2$ and the third intersection point $Q_3$ and equal to or larger than 10 μm.

For example, in the embodiment, as shown in FIG. **6**, one of the first wiring electrodes **141** is coupled to a part between the corner portion C**1** and the second intersection point $Q_2$. Further, the line width of the first wiring electrode **141** is smaller than the dimension from the corner portion C**1** to the second intersection point $Q_2$.

Note that the coupling position of the first wiring electrode **141** is explained with a focus on the corner portion neighborhood range P**1** containing the corner portion C**1** located at the −X−Y side, and the same applies to the other corner portions C**2**, C**3**, C**4** and the first wiring electrodes **141** are coupled to corresponding corner portion neighborhood ranges P**2**, P**3**, P**4**.

In the embodiment, in the piezoelectric element **13**, when a voltage is applied between the first electrode **131** and the second electrode **133**, the piezoelectric element **13** deforms the vibrating portion **12**A around the point of the center of gravity O at the center. That is, in FIG. **6**, the piezoelectric element **13** deforms in the same amount of deformation at the respective points on the virtual circle R, and the amount of deformation outside the virtual circle R is smaller than those at the respective points on the virtual circle R. Therefore, in the corner portion neighborhood ranges P**1** to P**4**, the amounts of deformation are smaller than those at the midpoints of the respective sides of the piezoelectric element **13**. Accordingly, the first wiring electrodes **141** are coupled to the corner portion neighborhood ranges P**1** to P**4**, and thereby, for example, compared to the case where the first wiring electrodes **141** are coupled to vicinities of the midpoints of the respective sides of the piezoelectric element **13**, the amounts of deformation of the first wiring electrodes **141** when the piezoelectric element **13** deforms are smaller and disconnection of the first wiring electrodes **141** due to deformation can be suppressed.

Returning to FIG. **5**, the first bypass electrode **151** will be explained.

The first bypass electrode **151** includes first coupling portion **151**A formed to be longitudinal along the X direction in positions overlapping with the wall portions **11**B and first connecting portion **151**B placed along the Y direction in positions overlapping with the wall portions **11**B in the plan view.

In the embodiment, as described above, the respective first electrodes **131** of the piezoelectric elements **13** arranged in the Y direction are coupled by the first wiring electrodes **141** at the same potential. Therefore, when these respective piezoelectric elements **13** arranged in the Y direction form a single piezoelectric element column, in the embodiment, a plurality of the piezoelectric element columns are arranged in the X direction. The first coupling portions **151**A of the first bypass electrode **151** are coupled to the first wiring electrodes **141** of a predetermined number of piezoelectric element columns as shown in FIG. **6**. When n piezoelectric elements **13** are provided along the Y direction in the single piezoelectric element column and m piezoelectric element columns are coupled by the first bypass electrodes **151**, the first electrodes **131** of the m×n piezoelectric elements **13** are at the same potential and the ultrasonic transducers Tr containing these piezoelectric elements **13** form a single channel CH. Accordingly, in the embodiment, as shown in FIG. **5**, the ultrasonic sensor **10** has a structure in which a plurality of the channels CH are placed in a one-dimensional array structure along the X direction.

Further, the first connecting portion **151**B is placed at the +X side or −X side in each channel CH and connects the respective first coupling portions **151**A. For example, as shown in FIG. **5**, the first coupling portions **151**A of the channel CH placed in the odd-numbered position along the X direction are connected by the first connecting portion **151**B placed at the −X side of the channel CH. The first coupling portions **151**A of the channel CH placed in the even-numbered position along the X direction are connected by the first connecting portion **151**B placed at the +X side of the channel CH. These first connecting portions **151**B are coupled to respectively corresponding drive terminals **153** and coupled to the drive circuit **30** via the drive terminals **153**. Thereby, respectively independent drive signals can be input from the drive circuit **30** to the respective channels CH, and reception signals output from the respective channels can be respectively independently detected.

On the other hand, the second wiring electrode **142** is an electrode coupled to the outer peripheral edges of the second electrodes **133**, and, as shown in FIG. **2**, extended from a position overlapping with the opening portion **11**A in the plan view to a position not overlapping with the opening portion **11**A, i.e., a position overlapping with the wall portion **11**B. In the embodiment, the second wiring electrode **142** is placed along the X direction and couples the second electrodes **133** arranged in the X direction within the same channel CH.

Further, the second wiring electrode **142** is coupled to center parts in the sides at the ±X sides of the second electrodes **133** and the line width as a width in the Y direction is equal to or smaller than the width of the second electrode **133** in the Y direction.

That is, in the embodiment, the outer peripheral edge of the second electrode **133** is located outside of the outer peripheral edge of the piezoelectric element **13**, and thus, the amounts of deformation at the respective points of the outer peripheral edge of the second electrode **133** are smaller than the amounts of deformation at the respective points of the outer peripheral edge (outline) of the piezoelectric element **13** when a voltage is applied to the piezoelectric element **13**. Therefore, even when the second wiring electrode **142** is coupled to the center parts of the sides of the second electrode **133**, the second wiring electrode **142** is not disconnected.

The second bypass electrode **152** is provided in a position overlapping with the wall portions **11**B in the plan view. Further, the second bypass electrode **152** includes a second coupling portion **152**A formed to be longitudinal along the Y direction and a second connecting portion **152**B placed as shown in FIG. **5**.

As shown in FIG. **5**, the second coupling portion **152**A is placed between the odd-numbered channel CH and the even-numbered channel CH, and coupled to the second wiring electrodes **142** placed in the two channels CH placed with the second coupling portion **152**A in between.

Further, the second connecting portion **152**B is provided at the opposite side to the side at which the drive terminals **153** and common terminals **154** are placed, and connects all of the second coupling portions **152**A.

That is, in the embodiment, the second electrodes **133** of all piezoelectric elements **13** of the ultrasonic sensor **10** are at the same potential. Further, the second bypass electrodes **152** are coupled to the drive circuit **30** via the common terminals **154**, and the respective second electrodes **133** are maintained at a predetermined reference potential by the drive circuit **30**.

The above described first bypass electrodes **151** and second bypass electrodes **152** are placed in positions overlapping with the wall portions **11**B with a plurality of the electrodes as one set. For example, in FIGS. **2** and **5**, three first bypass electrodes **151** as one set form a bundle of electrodes and three second bypass electrodes **152** as one set form a bundle of electrodes. It is preferable that the dimension between the first bypass electrodes **151** forming the bundle of electrodes and the dimension between the second bypass electrodes **152** are equal to or larger than 5 μm and equal to or smaller than the line width of the first wiring electrode **141**.

The line width of each first bypass electrode **151** forming the bundle of electrodes and the line width of each second bypass electrode **152** forming the bundle of electrodes are formed to be the same width as the line width of the first wiring electrode **141**.

Note that, though the detailed illustration is omitted, Au wires are placed on the respective three first bypass electrodes **151** as one set and respective three second bypass electrodes **152** as one set. The three electrodes are covered by the Au wires, and thereby, electrical resistance in the bypass electrodes **15** can be reduced and attenuation of signal voltages can be suppressed. In FIGS. **2** and **5**, illustration of the Au wires covering the bundles of electrodes is omitted.

In the embodiment, in the respective channels CH, protective electrodes **155** are placed with a plurality of the electrodes as one set like the first bypass electrodes **151** and the second bypass electrodes **152** in positions overlapping with the wall portions **11**B between the opening portions **11**A adjacent to each other in the X direction. For example, in the example shown in FIG. **2**, in the plan view, three of the protective electrodes **155** parallel in the Y direction are provided respectively in the positions overlapping with the wall portions **11**B between the opening portions **11**A adjacent to each other in the X direction.

Configuration of Control Unit **20**

The control unit **20** includes the drive circuit **30** that drives the ultrasonic sensor **10** and a calculation unit **40**. Further, in addition, a memory unit that stores various kinds of data, various programs, etc. for control of the distance measuring apparatus **100** may be provided in the control unit **20**.

The drive circuit **30** is a circuit board on which a driver circuit for controlling driving of the ultrasonic sensor **10** is provided, and includes e.g. a reference potential circuit **31**, a switching circuit **32**, a transmitting circuit **33**, and a receiving circuit **34** as shown in FIG. **1**.

The reference potential circuit **31** is coupled to the common terminal **154** of the ultrasonic sensor **10** and applies a reference potential to the second electrodes **133**. As the reference potential, e.g. −3 V or the like may be exemplified.

The switching circuit **32** is coupled to the drive terminal **153** of the ultrasonic sensor **10**, the transmitting circuit **33**, and the receiving circuit **34**. The switching circuit **32** includes a switching circuit and switches between transmission coupling for coupling the drive terminal **153** and the transmitting circuit **33**, and reception coupling for coupling the drive terminal **153** and the receiving circuit **34**.

The transmitting circuit **33** is coupled to the switching circuit **32** and the calculation unit **40** and, when the switching circuit **32** is switched to the transmission coupling, outputs drive signals in pulse waveforms to the piezoelectric elements **13** of the respective ultrasonic transducers Tr and transmits ultrasonic wave from the ultrasonic sensor **10** based on the control of the calculation unit **40**.

The receiving circuit **34** is coupled to the switching circuit **32** and the calculation unit **40**, to which the reception signals from the respective piezoelectric elements **13** are input when the switching circuit **32** is switched to the reception coupling. The receiving circuit **34** includes e.g. a linear noise amplifier, A/D converter, etc., and performs respective signal processing of conversion of the input reception signals into digital signals, removal of noise components, amplification to desired signal levels, etc. and outputs the processed reception signals to the calculation unit **40**.

The calculation unit **40** includes e.g. a CPU (Central Processing Unit) or the like, and controls the ultrasonic sensor **10** via the drive circuit **30** and performs transmission and reception processing of ultrasonic wave using the ultrasonic sensor **10**.

That is, the calculation unit **40** switches the switching circuit **32** to the transmission coupling, drives the ultrasonic sensor **10** from the transmitting circuit **33**, and performs transmission processing of ultrasonic wave. Further, the calculation unit **40** switches the switching circuit **32** to the reception coupling immediately after the transmission of ultrasonic wave, and receives the reflected wave reflected by an object by the ultrasonic sensor **10**. Then, the calculation unit **40** calculates a distance from the ultrasonic sensor **10** to the object by the ToF (Time of Flight) method using e.g. a time from a transmission time at which the ultrasonic wave is transmitted from the ultrasonic sensor **10** to the reception of the reception signal and the acoustic velocity in the air.

Manufacturing Method of Ultrasonic Sensor

Next, a manufacturing method of the ultrasonic sensor **10** of the embodiment will be explained.

FIG. **7** shows the respective steps for manufacturing the ultrasonic sensor **10**.

In the manufacture of the ultrasonic sensor **10**, first, a base material substrate for formation of the substrate **11** and the vibrating plate **12** is prepared. The base material substrate is a parallel plate having parallel two flat surfaces and formed using Si.

Then, one of the parallel two flat surfaces of the base material substrate is thermally oxidized. Thereby, the thermally oxidized one surface becomes the first vibrating plate

121 formed by $SiO_2$, and the unoxidized residual part becomes the substrate **11**. A boundary between the substrate **11** and the first vibrating plate **121** becomes the first surface **111**. Further, a Zr film is formed on the first vibrating plate **121**, thermally oxidized, and the second vibrating plate **122** of $ZrO_2$ is formed. Thereby, as shown by the first step in FIG. **7**, the vibrating plate **12** is formed on the substrate **11**.

Then, a conducting member is stacked on the vibrating plate **12**. The conducting member is not particularly limited, but a metal material, metal alloy material, conductive oxide, or the like may be used. Further, a plurality of materials may be layered as the conducting member and, in the embodiment, a layered electrode of Ir and Ti is formed.

Then, a mask pattern for formation of the first electrode **131**, the first wiring electrode **141**, the first bypass electrode **151**, the second bypass electrode **152**, and the protective electrode **155** is formed on the conducting member and, as shown by the second step in FIG. **7**, the respective electrodes are patterned by etching. The first electrode **131**, the first wiring electrode **141**, the first bypass electrode **151**, the second bypass electrode **152**, and the protective electrode **155** are formed using the same material at the same time. As shown by the second step in FIG. **7**, the first electrode **131**, the first wiring electrode **141**, the first bypass electrode **151**, the second bypass electrode **152**, and the protective electrode **155** are formed. Note that, in FIG. **7**, only the first electrode **131** is shown, but the illustration of the first wiring electrode **141**, the first bypass electrode **151**, the second bypass electrode **152**, and the protective electrode **155** is omitted.

Note that, in this regard, it is preferable to stop etching on the surface of the second vibrating plate **122**, however, actually, as shown by the second step in FIG. **7**, the part with no electrode placed thereon is slightly etched. Here, in the embodiment, the protective electrode **155** is formed in the part with no bypass electrode **15** or first wiring electrode **141** formed thereon of the parts overlapping with the wall portions **11**B in the plan view. Thereby, inconvenience of excessive etching of the second vibrating plate **122** is suppressed.

Then, the piezoelectric material **132** is formed on the vibrating plate **12**. For the piezoelectric material **132**, a piezoelectric material of transition metal oxide having a perovskite structure or the like may be used, and PZT is used in the embodiment. Specifically, an application step of applying a PZT solution to cover the vibrating plate **12** using a solution technique and a firing step of firing the applied PZT solution are performed at a plurality of times, and thereby, a piezoelectric material layer having a predetermined thickness is formed.

Then, a mask pattern for formation of the piezoelectric material **132** is formed on the piezoelectric material layer and, as shown by the third step in FIG. **7**, patterned by etching.

Here, the bypass electrode **15** coupling the wiring electrode **14** coupled to the piezoelectric element **13** and the terminal part (the drive terminal **153** and the common electrode **154**) tends to be longer in wiring distance. Accordingly, in related art, the line width of the bypass electrode is made larger than that of the wiring electrode to suppress increase in electrical resistance. In this regard, it is preferable that the line width of the wiring electrode coupled to the piezoelectric element **13** and placed over inside and outside of the vibrating portion **12**A is made as small as possible to reduce the influence on the vibration of the vibrating portion **12**A. Further, the length of the wiring electrode is shorter and, even when the line width is made smaller and the electrical resistance increases, the influence on driving of the piezoelectric element **13** is smaller. Therefore, in related art, the electrode pattern is formed so that the line width of the wiring electrode may be made smaller than the line width of the bypass electrode.

If PZT is left in the bypass electrode **15**, particularly, conduction may be lost due to coupling failure between the second bypass electrode **152** and the second wiring electrode **142**. Accordingly, at the step of patterning the piezoelectric material **132** by etching, it is necessary to take a sufficient time for etching so that PZT may not be left on the bypass electrode **15**.

However, when the line width of the bypass electrode is made larger than the line width of the wiring electrode as in related art, the etching rate of PZT on the wiring electrode is faster than the etching rate of PZT on the bypass electrode. Accordingly, the PZT on the wiring electrode is removed earlier than the PZT on the bypass electrode. Therefore, when etching is continued until the PZT on the bypass electrode is completely removed, the wiring electrode is inconveniently etched. In this case, the wiring electrode may be disconnected.

On the other hand, in the embodiment, as described above, the first bypass electrodes **151** and the second bypass electrodes **152** having the same line width as those of the first wiring electrodes **141** are formed and the bundles of electrodes with the three first bypass electrodes **151** as one set and the three second bypass electrodes **152** as one set are formed.

Accordingly, the etching rate of PZT on the first wiring electrode **141**, the etching rate of PZT on the first bypass electrodes **151**, and the etching rate of PZT on the second bypass electrodes **152** are the same. Therefore, the inconvenience of etching of the first wiring electrode **141** by excessive etching is suppressed and disconnection of the first wiring electrode **141** is suppressed. Note that the part with no electrode formed thereon of the second vibrating plate **122** is slightly etched as shown by the third step in FIG. **7**.

As described above, the piezoelectric material **132** is patterned, then, the conducting member is formed on the vibrating plate **12**, the mask pattern for formation of the second electrode **133** and the second wiring electrode **142** is formed, and the second electrode **133** and the second wiring electrode **142** are formed by etching.

Further, though not shown, the Au electrodes are formed on the three first bypass electrodes **151** as one set and the three second bypass electrodes **152** as one set, and the respective bypass electrodes **15** are reinforced by the Au electrodes.

Furthermore, the protective film **134** covering the piezoelectric element **13** is formed. Thereby, as shown by the fourth step in FIG. **7**, formation of the basic structure containing the piezoelectric element **13** on the vibrating plate **12** is completed.

Then, the second surface **112** at the opposite side to the first surface **111** of the substrate **11** is cut and polished into a desired thickness and a mask pattern for formation of the opening portion **11**A in the second surface **112** is formed, and the opening portion **11**A is formed by etching using the first vibrating plate **121** of $SiO_2$ as an etching stopper. Thereby, as shown by the fifth step in FIG. **7**, the ultrasonic sensor **10** is manufactured.

## Functions and Effects of Embodiment

The distance measuring apparatus **100** of the embodiment includes the ultrasonic sensor **10** and the control unit **20** that controls the ultrasonic sensor **10**. Further, the ultrasonic sensor **10** includes the substrate **11** having the opening portions **11**A penetrating from the first surface **111** to the second surface **112**, the vibrating plate **12** provided on the substrate **11** to close the opening portions **11**A, and the piezoelectric elements **13** provided on the vibrating plate **12** in the positions overlapping with the opening portions **11**A in the plan view. Furthermore, the first wiring electrodes **141** as the coupling electrodes extended from the positions overlapping with the opening portions **11**A to the positions not overlapping with the opening portions **11**A and having the line widths smaller than the widths of the piezoelectric elements **13** are coupled to the piezoelectric elements **13**.

In the embodiment, the piezoelectric element **13** is formed in the rectangular shape in the plan view and has the outline containing the corner portion C**1** and the first line portion E**1** and the second line portion E**2** with the corner portion C**1** in between. The first wiring electrode **141** is coupled to the corner portion neighborhood range P**1** from the second intersection point $Q_2$ through the corner portion C**1** to the third intersection point $Q_3$ in the outline of the piezoelectric element **13**.

The corner portions C**1** to C**4** in the piezoelectric element **13** are singularities where the piezoelectric element **13** is least likely to deform when the drive voltage is applied to the piezoelectric element **13**. In the embodiment, the first wiring electrodes **141** are provided in the corner portion neighborhood ranges P**1** to P**4** around the singularities, and thus, the first wiring electrodes **141** are unlikely to deform when the drive voltage is applied to the piezoelectric element **13** and breakage of the first wiring electrodes **141** is suppressed. Thereby, the ultrasonic sensor **10** with higher wiring reliability may be obtained. Therefore, reliability in the distance measuring apparatus **100** including the ultrasonic sensor **10** is improved.

In the embodiment, the piezoelectric element **13** includes the first electrode **131**, the piezoelectric material **132** covering the first electrode **131**, and the second electrode **133** provided on the piezoelectric material **132** at the opposite side to the first electrode **131**, and the first electrode **131** is provided inside of the outer peripheral edge of the second electrode **133** in the plan view. Therefore, the piezoelectric element **13** is formed by the entire first electrode **131**, a part of the piezoelectric material **132** overlapping with the first electrode **131** in the plan view, and a part of the second electrode **133** overlapping with the first electrode **131** in the plan view.

In the configuration, the second electrode **133** covers a part of the piezoelectric material **132**, and thus, the piezoelectric material **132** exposed to outside in a smaller region and it is only necessary to provide the protective film **134** to cover the exposed region. The configuration may be simplified.

Here, the entire first electrode **131** forms the piezoelectric element **13**, and the outer peripheral edge of the first electrode **131** coincides with the outer peripheral edge of the piezoelectric element **13** in the plan view. In the configuration, when the drive voltage is applied to the piezoelectric element **13**, the amount of deformation of the first electrode **131** is larger, however, breakage of the first wiring electrodes **141** may be suppressed because the first wiring electrodes **141** are coupled to the corner portion neighborhood ranges P**1** to P**4** as described above.

The ultrasonic sensor **10** of the embodiment includes the drive terminal **153**, the common terminal **154**, the first bypass electrode **151** that couples the drive terminal **153** and the first wiring electrode **141**, and the second bypass electrode **152** that couples the common terminal **154** and the second wiring electrode **142**. The line widths of the first bypass electrode **151** and the second bypass electrode **152** are formed to be the same width as the line width of the first wiring electrode **141**.

In the configuration, disconnection of the first wiring electrode **141** in the manufacturing of the ultrasonic sensor **10** may be suppressed. That is, when the thin-film type piezoelectric element **13** is formed on the vibrating plate **12** like the ultrasonic sensor **10** of the embodiment, usually, the first electrode **131**, the first wiring electrode **141**, and the bypass electrode **15** are formed, then, the piezoelectric material layer is formed to cover these electrodes, and the piezoelectric material **132** is formed by etching of the piezoelectric material layer. In the formation, it is necessary to etch the piezoelectric material layer so that the piezoelectric material layer may not be left in a part of the first wiring electrode **141** and the bypass electrode **15**. Here, when the line width of the bypass electrode **15** is larger than that of the first wiring electrode **141**, the piezoelectric material layer on the first wiring electrode **141** is removed earlier. Therefore, when etching is continued until the piezoelectric material layer on the bypass electrode **15** is removed, part of the first wiring electrode **141** is also removed by the etching and the line width of the first wiring electrode **141** becomes thinner and the electrode may be disconnected. On the other hand, in the embodiment, the piezoelectric material layers on the first wiring electrode **141** and the bypass electrode **15** may be removed substantially at the same time and inconvenience of thinner line width and disconnection of the first wiring electrode **141** may be suppressed.

## Second Embodiment

In the above described first embodiment, the example in which the first electrode **131** is provided inside of the outer peripheral edge of the piezoelectric material **132** and the peripheral edge of the second electrode **133** and the entire first electrode **131** forms a part of the piezoelectric element **13** is shown.

On the other hand, the second embodiment is different from the first embodiment in that the first electrode is larger than the second electrode and the second electrode is provided inside of the outer peripheral edge of the first electrode.

FIG. **8** is the partially enlarged plan view of a part of an ultrasonic sensor **10**A according to the second embodiment. Note that, in the following description, the same configurations as those of the previously described items have the same signs and the explanation thereof will be omitted or simplified.

As shown in FIG. **8**, in the embodiment, like the ultrasonic sensor **10** of the first embodiment, the substrate **11** having the opening portions **11**A, the vibrating plates **12**, and the piezoelectric elements **13** are provided.

Like the first embodiment, the piezoelectric element **13** of the embodiment is also formed by a part in which a first electrode **131**A, a piezoelectric material **132**A, and a second electrode **133**A overlap in the plan view.

Here, in the embodiment, the first electrode **131**A has larger widths with respect to the X direction and the Y direction than the first electrode **131** in the first embodiment.

Further, the piezoelectric material **132**A has a larger width with respect to the X direction than the first electrode **131**A. Therefore, the −X side end portion of the piezoelectric material **132**A is located closer to the −X side than the −X side end portion of the first electrode **131**A, and the +X side end portion of the piezoelectric material **132**A is located closer to the +X side than the +X side end portion of the first electrode **131**A.

On the other hand, in the embodiment, the piezoelectric material **132**A has a smaller width with respect to the Y direction than the first electrode **131**A and located inside of the ±Y end portions of the first electrode **131**A. That is, the −Y side end portion of the piezoelectric material **132**A is located closer to the +Y side than the −Y side end portion of the first electrode **131**A, and the +Y side end portion of the piezoelectric material **132**A is located closer to the −Y side than the +Y side end portion of the first electrode **131**A.

Note that, here, the example in which the width of the piezoelectric material **132**A is smaller than that of the first electrode **131**A with respect to the Y direction is shown, however, the configuration is not limited to that. For example, like the first embodiment, the piezoelectric material **132**A may be provided to cover the entire first electrode **131**A.

The second electrode **133**A of the embodiment is smaller than the first electrode **131**A and placed inside of the outer peripheral edge of the first electrode **131**A in the plan view.

Therefore, in the embodiment, the entire second electrode **133**A, a part of the first electrode **131**A, and a part of the piezoelectric material **132**A overlap in the plan view and form the piezoelectric element **13**.

Further, in the embodiment, the coupling electrodes coupled to the piezoelectric material **132** are second wiring electrodes **142**A coupled to the second electrode **133**A. Like the first wiring electrodes **141** in the first embodiment, the second wiring electrodes **142**A are coupled to the corner portion neighborhood ranges P**1** to P**4** within predetermined ranges from the corner portions C**1** to C**4** of the piezoelectric element **13**.

On the other hand, a first wiring electrode **141**A in the embodiment is an electrode coupled to the outer peripheral edge of the first electrode **131**A. The first wiring electrode **141**A is coupled to center parts in the sides at the ±Y sides of the first electrode **131**A.

The line width of the first wiring electrode **141**A is the same as that of the first embodiment and preferably equal to or larger than 10 μm and equal to or smaller than the length of the line segment connecting the second intersection point $Q_2$ and the third intersection point $Q_3$. That is, the line width of the first wiring electrode **141**A formed directly on the vibrating plate **12**A is made smaller than the width in the X direction in the piezoelectric element **13**, and thereby, the influence on the vibration of the vibrating portion **12**A may be reduced.

Furthermore, in the embodiment, the outer peripheral edge of the first electrode **131**A is located outside of the outer peripheral edge of the piezoelectric element **13**, and thus, the amounts of deformation at the respective points of the outer peripheral edge of first electrode **131**A are smaller than the amounts of deformation at the respective points on the outer peripheral edge (outline) of the piezoelectric element **13** when a voltage is applied to the piezoelectric element **13**. Therefore, even when the first wiring electrode **141**A is coupled to the center parts of the sides of the first electrode **131**A and the line width thereof is made smaller, the first wiring electrode **141**A is not disconnected.

In the embodiment, the same functions and effects as those of the above described first embodiment may be exerted.

That is, in the embodiment, the second wiring electrodes **142**A are coupled to the corner portions C**1** to C**4** as singularities where the piezoelectric element **13** is least likely to deform when the drive voltage is applied to the piezoelectric element **13**. Thus, the second wiring electrodes **142**A are unlikely to deform when the drive voltage is applied to the piezoelectric element **13** and breakage of the second wiring electrodes **142**A is suppressed. Thereby, the ultrasonic sensor **10**A with higher wiring reliability may be obtained.

## Third Embodiment

Next, the third embodiment will be explained.

In the first embodiment, the example in which the piezoelectric element **13** and the first electrode **131** coincide in the plan view and, in the second embodiment, the example in which the piezoelectric element **13** and the second electrode **133**A coincide in the plan view are shown. On the other hand, in the third embodiment, both the first electrode **131** and the second electrode **133** coincide with the piezoelectric element **13** in the plan view.

FIG. **9** is the partially enlarged plan view of a part of an ultrasonic sensor **10**B according to the third embodiment.

As shown in FIG. **9**, in the embodiment, like the ultrasonic sensor **10** of the first embodiment, the substrate **11** having the opening portions **11**A, the vibrating plates **12**, and the piezoelectric elements **13** are provided.

Like the first embodiment, the piezoelectric element **13** of the embodiment is also formed by a part in which a first electrode **131**B, a piezoelectric material **132**B, and a second electrode **133**B overlap in the plan view.

Here, in the embodiment, the first electrode **131**B and the piezoelectric material **132**B have the same shapes and sizes as those in the first embodiment.

The second electrode **133**B is formed in the same shape as the first electrode **131**B and placed to overlap with the first electrode **131**B in the plan view.

That is, in the embodiment, the piezoelectric element **13** is formed by the entire first electrode **131**B, the entire second electrode **133**B, and a part of the piezoelectric material **132**B overlapping in the plan view.

Further, in the embodiment, the coupling electrodes coupled to the piezoelectric element **13** include first wiring electrodes **141**B as first coupling electrodes and second wiring electrodes **142**B as second coupling electrodes.

Like the first embodiment, the first wiring electrodes **141**B are coupled to ±Y sides in the first electrode **131**B overlapping with the corner portion neighborhood ranges P**1** to P**4** of the piezoelectric element **13** in the plan view and extended along the Y direction.

Like the second embodiment, the second wiring electrodes **142**B are coupled to ±X sides of the second electrode **133**B overlapping with the corner portion neighborhood ranges P**1** to P**4** of the piezoelectric element **13** in the plan view and extended along the X direction.

In the embodiment, the same functions and effects as those of the above described first embodiment and second embodiment may be exerted.

That is, in the embodiment, the first wiring electrodes **141**B and the second wiring electrodes **142**B are coupled to the corner portions C**1** to C**4** as singularities where the piezoelectric element **13** is least likely to deform when the drive voltage is applied to the piezoelectric element **13**. Thus, the first wiring electrodes **141**B and the second wiring electrodes **142**B are unlikely to deform when the drive voltage is applied to the piezoelectric element **13** and breakage of the first wiring electrodes **141**B and the second wiring electrodes **142**B is suppressed. Thereby, the ultrasonic sensor **10**B with higher wiring reliability may be obtained.

MODIFIED EXAMPLES

The present disclosure is not limited to the above described respective embodiments. The present disclosure includes modifications and improvements within the range in which the purpose of the present disclosure may be achieved and configurations obtained by appropriate combinations of the respective embodiments or the like.

Modified Example 1

In the first embodiment, the example in which the second wiring electrode **142** is coupled to the center parts of the second electrode **133** is shown, however, the configuration is not limited to that. For example, the electrode may be coupled to corner portion neighborhoods of the second electrode **133**. The same applies to the second embodiment, and the first wiring electrode **141**A may be coupled to corner portion neighborhoods of the first electrode **131**A.

Modified Example 2

In the examples shown in the first embodiment to the third embodiment, the example in which the piezoelectric element **13** has a square shape is shown, however, the configuration is not limited to that.

For example, as shown in FIG. **10**, a piezoelectric element **13**A having a hexagonal shape in the plan view may be employed. Also, in this case, an intersection point of a first virtual line connecting each corner portion C and a center of a virtual circle R with the virtual circle R is a first intersection point $Q_1$, and intersection points of a tangent line of the virtual circle R at the first intersection point with respective sides of the piezoelectric element **13**A are a second intersection point $Q_2$ and a third intersection point $Q_3$. A first wiring electrode **141**C is coupled to a corner portion neighborhood range P from the second intersection point $Q_2$ to the third intersection point $Q_3$.

In the example of FIG. **10**, the first wiring electrodes **141**C coupled to the first electrode **131**C are coupling electrodes coupled directly to the piezoelectric element **13**A. When the second electrode **133**C and the piezoelectric element **13**A coincide like those in the second embodiment and the third embodiment, the second wiring electrode **142**C may be configured to couple to the corner portion neighborhood range P of the second electrode **133**C as a coupling electrode.

Note that the virtual circle in the present disclosure is not necessarily a perfect circle. For example, in an example shown in FIG. **11**, a shape of the piezoelectric element **13**B in the plan view is a rectangular shape. In this case, an oval inscribed in the respective sides of the rectangular shape is a virtual circle $R_2$. Therefore, an intersection point of the oval virtual circle $R_2$ with a first virtual line $L_1$ connecting a point of the center of gravity O and a corner portion C is a first intersection point $Q_1$, and a tangent line of the virtual circle $R_2$ at the first intersection point $Q_1$ is a second virtual line $L_2$.

In the example of FIG. **11**, like the first embodiment, an entire first electrode **131**D overlaps with the piezoelectric element **13**B in the plan view. In this case, a first wiring electrode **141**D as a coupling electrode is coupled to a corner portion neighborhood range P from the second intersection point $Q_2$ to the third intersection point $Q_3$ of the first electrode **131**D overlapping with the piezoelectric element **13**B.

Further, the plan view shape of the piezoelectric element is not necessarily the polygonal shape like those in the above described embodiments, FIG. **10**, and FIG. **11**. The plan view shape of the piezoelectric element may be e.g. a sector shape as shown in FIG. **12**.

In the example shown in FIG. **12**, two lines as chords of a piezoelectric element **13**C in the sector shape are a first line portion E**1** and a second line portion E**2**. Further, a virtual circle $R_3$ is a circle inscribed in the chords and an arc of the sector shape.

Like the first embodiment, FIG. **12** shows an example in which an entire first electrode **131**E overlaps with the piezoelectric element **13**C in the plan view, and a first wiring electrode **141**E as a coupling electrode is coupled to a corner portion neighborhood range P from a second intersection point $Q_2$ to a third intersection point $Q_3$ of the first electrode **131**E overlapping with the piezoelectric element **13**C.

Note that, in the examples shown in FIGS. **11** and **12**, the coupling electrodes are the first wiring electrodes **141**D, **141**E, however, a second wiring electrode may be a coupling electrode like the second embodiment, and both the first wiring electrode and the second wiring electrode may be coupling electrodes like the third embodiment.

Modified Example 3

In the first embodiment, the example in which the first wiring electrodes **141** are coupled at the ±Y sides of the first electrode **131** is shown, however, the configuration is not limited to that. As described above, it is only necessary that the first wiring electrodes **141** are coupled to the corner portion neighborhood ranges P**1** to P**4**. Therefore, for example, as shown in FIG. **11**, the first wiring electrode **141** may be coupled from the side at the −Y side to the side at the −X side of the first electrode **131** or the first wiring electrode **141** may be coupled from the side at the −Y side to the side at the +X side of the first electrode **131**. The same applies to the second embodiment.

Modified Example 4

In the above described first embodiment, the distance measuring apparatus **100** is exemplified as an example of an ultrasonic apparatus, however, the apparatus is not limited to that. For example, the ultrasonic apparatus may be applied to an ultrasonic measuring apparatus that measures inner cross-sectional images of a structure according to transmission and reception results of ultrasonic wave or the like.

In addition, a specific structure when the present disclosure is embodied may be configured by an appropriate combination of the above described embodiments and modified examples within a range in which the purpose of the present disclosure may be achieved, or may be appropriately changed to another structure.

What is claimed is:

**1**. An ultrasonic sensor comprising:

a substrate having a first surface and a second surface in a front-back relationship with the first surface and having an opening portion penetrating from the first surface to the second surface;

a vibrating plate provided on the first surface of the substrate and covering the opening portion;

a piezoelectric element provided in a position overlapping with the opening portion in a plan view as seen from a direction from the first surface to the second surface in the vibrating plate; and

a coupling electrode coupled to the piezoelectric element, extended from a position overlapping with the opening portion to a position not overlapping with the opening portion in the plan view, and having a line width smaller than a width of the piezoelectric element, wherein

the piezoelectric element has an outline including a first line portion, a second line portion, and a corner portion coupling the first line portion and the second line portion in the plan view,

when an intersection point of a first virtual line connecting a point of a center of gravity of the piezoelectric element and the corner portion with a virtual circle inscribed in the outline of the piezoelectric element is a first intersection point, an intersection point of a tangent line of the virtual circle at the first intersection point with the first line portion is a second intersection point, and an intersection point of the tangent line of the virtual circle at the first intersection point with the second line portion is a third intersection point, the coupling electrode is coupled to a corner portion within a range from the second intersection point through the corner portion to the third intersection point in the outline of the piezoelectric element.

**2**. The ultrasonic sensor according to claim **1**, further comprising:

a first electrode provided on the vibrating plate;

a piezoelectric material provided on the first electrode at an opposite side to the vibrating plate and covering the first electrode; and

a second electrode provided on the piezoelectric material at an opposite side to the first electrode, wherein

the first electrode is provided inside of an outer peripheral edge of the second electrode in the plan view,

the piezoelectric element is formed by a part in which the first electrode, the piezoelectric material, and the second electrode overlap in the plan view, and

the coupling electrode is an electrode coupled to the first electrode.

**3**. The ultrasonic sensor according to claim **1**, further comprising:

a first electrode provided on the vibrating plate;

a piezoelectric material provided on the first electrode at an opposite side to the vibrating plate; and

a second electrode provided on the piezoelectric material at an opposite side to the first electrode, wherein

the second electrode is provided inside of an outer peripheral edge of the first electrode in the plan view,

the piezoelectric element is formed by a part in which the first electrode, the piezoelectric material, and the second electrode overlap in the plan view, and

the coupling electrode is an electrode coupled to the second electrode.

**4**. The ultrasonic sensor according to claim **1**, further comprising:

a first electrode provided on the vibrating plate;

a piezoelectric material provided on the first electrode at an opposite side to the vibrating plate; and

a second electrode provided on the piezoelectric material at an opposite side to the first electrode, wherein

the second electrode has the same shape as the first electrode and overlaps with the first electrode in the plan view,

the piezoelectric element is formed by a part in which the first electrode, the piezoelectric material, and the second electrode overlap in the plan view, and

the coupling electrode includes a first coupling electrode coupled to the first electrode and a second coupling electrode coupled to the second electrode.

**5**. The ultrasonic sensor according to claim **1**, further comprising:

a terminal portion coupled to a circuit board; and

a bypass electrode coupling the terminal portion and the coupling electrode, wherein

the line width of the coupling electrode and a line width of the bypass electrode are the same width.

**6**. An ultrasonic apparatus comprising:

the ultrasonic sensor according to claim **1**; and

a control unit that controls the ultrasonic sensor.

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